CHAPTER 3 Review

REFLECTING ON CHAPTER 3

- Tycho Brahe collected detailed astronomical data for 20 years.
- Johannes Kepler analyzed Brahe's data and developed three empirical equations that are now called "Kepler's laws."
  1. Planets follow elliptical paths.
  2. The areas swept out by a line from the Sun to a planet during a given time interval are always the same.
  3. $\frac{T^2}{r^3} = k$ or $\frac{T_A^2}{r_A^3} = \frac{T_B^2}{r_B^3}$
- Kepler's laws support Newton's law of universal gravitation.
- Newton extended the concept of gravity and showed that not only does it cause celestial bodies to attract each other, but also that all masses exert a mutually attractive force on each other.
- Newton's law of universal gravitation is written mathematically as $F_g = G\frac{m_1 m_2}{r^2}$.
- Newton's law of universal gravitation shows that the constant in Kepler's third law is given by $\frac{T^2}{r^3} = \frac{4\pi^2}{Gm_s}$.
- You can use the combination of Newton's law of universal gravitation and Kepler's third law to determine the mass of any celestial body that has one or more satellites.
- Cavendish used a torsion balance to determine the universal gravitational constant, G, in Newton's law of universal gravitation: $G = 6.67 \times 10^{-11}\ \text{N} \cdot \text{m}^2/\text{kg}^2$.
- Newton reasoned that if you shot a cannon ball from the top of a very high mountain and it went fast enough horizontally, it would fall exactly the same distance that Earth's surface would drop, due to the spherical shape. This is the correct theory about satellite motion.
- A satellite in a geostationary orbit appears to hover over one spot on Earth's surface, because it completes one cycle as Earth makes one revolution on its axis.
- Apparent weightlessness in orbiting spacecraft is due to the fact that the spacecraft and everything in it are falling toward Earth with exactly the same acceleration.
- The planets Neptune and Pluto were both discovered because their gravity perturbed the path of other planets.

Knowledge/Understanding

1. Distinguish between mass and weight.
2. Define **(a)** heliocentric and **(b)** geostationary.
3. State Kepler's laws.
4. Several scientists and astronomers had developed the concept that the attractive force on planets orbiting the Sun decreased with the square of the distance between a planet and the Sun. What was Newton's reasoning for including in his law of universal gravitation the magnitude of the masses of the planets? In what other ways did Newton's law of universal gravitation differ conceptually from the ideas of other scientists of his time?
5. Explain how Kepler's third law supports Newton's law of universal gravitation.
6. Is Kepler's constant a universal constant? That is, can it be applied to Jupiter's system of satellites or to other planetary systems? Explain.
7. How does a torsion balance work?
8. Explain whether it is possible to place a satellite into geosynchronous orbit above Earth's North Pole.

Inquiry

9. No reliable evidence supports the astrological claim that the motions of the stars and planets affect human activities. However, belief in astrology remains strong. Create an astrology defence or opposition kit. Include any or all of the following: arguments based on Newton's laws to refute or support astrological claims,

an experiment that tests the validity of birth horoscopes, a report on scientific studies of astrological claims and any findings, a summary of the success and failure of astrological predictions and a comparison of these to the success of predictions based on chance.

10. Devise an observational test (which will require a telescope) that will convince a doubting friend that Earth orbits the Sun.

11. Demonstrate the inverse square law form of the universal law of gravitation by calculating the force on a 100.0 kg astronaut who is placed at a range of distances from Earth's surface, out to several Earth radii. Make a graph of force versus position and comment on the results.

12. You often hear that the Moon's gravity, as opposed to the Sun's gravity, is responsible for the tides.

(a) Calculate the force of gravity that the Moon and the Sun exert on Earth. How does this appear to conflict with the concept stated above?

(b) Calculate the force of the Moon's gravity on 1.00×10^4 kg of water at the surface of an ocean on the same side of Earth as the Moon and on the opposite side of Earth from the Moon. Also, calculate the Moon's gravity on 1.00×10^4 kg of matter at Earth's centre. (Assume that the distance between the Moon's centre and Earth's centre is 3.84×10^8 m and that Earth's radius is 6.38×10^6 m.)

(c) Perform the same calculations for the Sun's gravity on these masses. (Use 1.49×10^{11} m for the distance between the centres of Earth and the Sun.)

(d) Examine your results from parts (b) and (c) and use them to justify the claim that the Moon's gravity is responsible for tides.

13. Many comets have been identified and the regularity of their return to the centre of the solar system is very predictable.

(a) From what you have learned about satellite motion, provide a logical explanation for the disappearance and reappearance of comets.

(b) Make a rough sketch of the solar system and add to it a probable comet path.

(c) What is the nature of the path taken by comets?

Communication

14. Consider a marble of mass m accelerating in free fall in Earth's gravity. Neglect air resistance and show that the marble's acceleration due to gravity is independent of its mass. (That is, you could use a bowling ball, a feather, or any other object in free fall and obtain the same result.) Hint: Equate Newton's universal law of gravitation to Newton's second law. Look up the values for Earth's mass and radius and use them in your acceleration equation to calculate the marble's acceleration. This number should be familiar to you!

15. Suppose that the Sun's mass was four times greater than it is now and that the radius of Earth's orbit was unchanged. Explain whether a year would be longer or shorter. By what factor would the period change? Explain in detail how you determined your answer.

16. **(a)** At what distance from Earth would an astronaut have to travel to actually experience a zero gravitational force, or "zero g"?

(b) Are astronauts in a space shuttle orbiting Earth subject to a gravitational force?

(c) How can they appear to be "weightless"?

17. A cow attempted to jump over the Moon but ended up in orbit around the Moon, instead. Describe how the cow could be used to determine the mass of the Moon.

18. Discuss what would happen to Earth's motion if the Sun's gravity was magically turned off.

19. The Sun gravitationally attracts Earth. Explain why Earth does not fall into the Sun.

Making Connections

20. Examine some Olympic records, such as those for the long-jump, shot-put, weightlifting, high-jump, javelin throw, 100 m dash, 400 m hurdles, and the marathon. How would you expect these records to change if the events

were performed under an athletic dome on the Moon?

21. Einstein once recalled his inspiration for the theory of general relativity from a sudden thought that occurred to him: "If a person falls freely, he will not feel his own weight.'' He said he was startled by the simple thought and that it impelled him toward a theory of gravitation. Although the mathematics of the general theory of relativity is advanced, its concepts are fascinating and have been described in several popular books. Research and write a short essay on the general theory of relativity, including a discussion of its predictions and tests, and how it supersedes (but does not replace) Newton's theory of gravitation.

Problems for Understanding

22. The gravitational force between two objects is 80.0 N. What would the force become if the mass of one object was halved and the distance between the two objects was doubled?

23. Two stars of masses $m*$ and $3m*$ are 7.5×10^{11} m apart. If the force on the large star is F, which of the following is the force on the small star?
(a) $F/9$ **(b)** $F/3$ **(c)** F **(d)** $3F$ **(e)** $9F$

24. For the above situation, if the acceleration of the small star is a, what is the acceleration of the large star?
(a) $a/9$ **(b)** $a/3$ **(c)** a **(d)** $3a$ **(e)** $9a$

25. **(a)** Use Newton's law of universal gravitation and the centripetal force of the Sun to determine Earth's orbital speed. Assume that Earth orbits in a circle.
(b) What is Earth's centripetal acceleration around the Sun?

26. Calculate the Sun's acceleration caused by the force of Earth.

27. A space shuttle is orbiting Earth at an altitude of 295 km. Calculate its acceleration and compare it to the acceleration at Earth's surface.

28. Orbital motions are routinely used by astronomers to calculate masses. A ring of high-velocity gas, orbiting at approximately 3.4×10^4 m/s at a distance of 25 light-years from the centre of the Milky Way, is considered to be evidence for a black hole at the centre. Calculate the mass of this putative black hole. How many times greater than the Sun's mass is it?

29. In a Cavendish experiment, two 1.0 kg spheres are placed 50.0 cm apart. Using the known value of G, calculate the gravitational force between these spheres. Compare this force to the weight of a flea.

30. The Hubble space telescope orbits Earth with an orbital speed of 7.6×10^3 m/s.
(a) Calculate its altitude above Earth's surface.
(b) What is its period?

31. The Moon orbits Earth at a distance of 3.84×10^8 m. What are its orbital velocity and period?

32. The following table gives orbital information for five of Saturn's largest satellites.

Satellite	Mean orbital radius (m)	Period (days)
Tethys	2.95×10^8	1.888
Dione	3.78×10^8	2.737
Rhea	5.26×10^8	4.517
Titan	1.221×10^9	15.945
Iapetus	3.561×10^9	79.331

(a) Determine whether these satellites obey Kepler's third law.
(b) If they obey Kepler's third law, use the data for the satellites to calculate an average value for the mass of Saturn.

33. Suppose the Oort cloud of comets contains 10^{12} comets, which have an average diameter of 10 km each.
(a) Assume that a comet is composed mostly of water-ice with a density of 1.00 g/cm^3 and calculate the mass of a comet.
(b) Calculate the total mass of the Oort cloud.
(c) Compare your mass of the Oort cloud to the mass of Earth and of Jupiter.